# Group Enabled Spatial Dissemination in Mobile Social Networks

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***Abstract*—Spatial dissemination allows a mobile user to send information to other mobile users who are or will appear at a user-defined region. It is typically done either via a centralized server or in a P2P fashion. In this paper, we design a new distributed spatial dissemination approach exploiting user groups in mobile social networks. Since users who are roughly in the same geographical location may obtain the same geographic relevant information or receive the same messages that have been disseminated, user groups can be utilized to reduce both the transmission cost and storage cost during the dissemination process. We have developed a technique to keep track of user group dynamics and designed methods to use group information in message replication, forwarding, and purging of the dissemination process. Our evaluation results show that the group enabled approach has very low transmission and storage costs.**

## I. Introduction

With the increasing popularity of mobile devices and advances in communication technologies, mobile users are able to disseminate geographic relevant information to other mobile users who are or will be at the same places. For instance, a tourist who notices that an entrance to an attraction is temporarily closed or a facility is temporarily out of service might disseminate the same information using his mobile phone to let other tourists going to the same place know this information. This geographic relevant message dissemination is spatial dissemination [1]. In spatial dissemination, a mobile user who disseminates a geographic relevant message has no knowledge about the message consumers. In addition, there is no communication infrastructure such as a central server to store the messages in a mobile P2P network. Therefore, mobile users need to store, carry, and forward messages in order to make sure the messages reach their consumers. Due to limited storage and communication resources on mobile devices, it is often desirable to reduce the cost of spatial dissemination.

This work is inspired by Sticker [1], a distributed spatial dissemination protocol that determines where, when, and how to distribute the messages among mobile devices. However, in Sticker, the message dissemination of each user is isolated. In other words, Sticker does not take into account the fact that a group of users who are in the same place or close enough might obtain the same geographic relevant information and disseminate the same message. For instance, there are several tourists who arrive at the entrance to an attraction at almost the same time, each of them notices that the entrance is closed and might send out the same information to notify incoming tourists. If they are aware that they have the same information, they do not need to disseminate duplicate messages or share the same message with each other, then the transmission cost could be reduced. Further, if the users who are together or close enough can be grouped in the message dissemination process, the messages can be maintained by user groups rather than individuals, so that the storage cost can also be reduced. In summary, the user groups can be exploited for more efficient spatial data dissemination to reduce the dissemination costs.

However, since people often move with no pre-configurations, mobile user grouping is dynamic. This work aims at exploiting the group dynamics in mobile social networks in terms of group size, group validity duration, and group location to design a more efficient spatial dissemination approach. To the best of our knowledge, none of existing work on group relevant services or applications as detailed in section II have the same goal as this work. We build upon Sticker [1] and design a group enabled spatial dissemination approach incorporating group dynamics. More specifically, mobile user group information is being used in three subproblems of spatial dissemination: replication, forwarding, and purging.

## II. Related Work

Group dynamics in social networks also refers to community dynamics [2], where the communities are densely connected groups of nodes within a social network such that connections between communities are sparse. In mobile social networks, there is lots of work studying group dynamics. For instances, [3] uses ego-graph to model mobile social networks and detect communities, and also makes contact recommendations to enhance group communication, [4] proposes a hypergraph to model the time-synchronized contacts of nodes from different communities as a social overlay, which can correctly capture what happens between communities, [5] [6] propose a two-phase framework for detecting network overlapping communities as well as tracking their evolution in dynamic mobile networks, which can be used to select overlapping boundary nodes as message receivers in mobile applications.

Group dynamics has been used in several mobile applications. [7] presents a location based mobile application to form and manage user groups by user proximity, [8] introduces a loosely defined user group in which group interaction provisions are based on asynchronous message passing, and

[9] proposes a group communication protocol that can provide applications with knowledge about who is a member of a group at any given time, where a group may split or distinct groups may merge.

Similarly, group dynamics has been applied to data dissemination services in mobile social networks. Data dissemination services disseminate information from certain locations or people throughout the entire network to reach more locations or people. For instances, [10] [11] present a service of floating content for information sharing in urban areas and address when content floats by characterizing availability of group information, [12] investigates the inefficiency of gossip based algorithms where message selection is based on the sender's own state in a random fashion, and then proposes an efficient dissemination strategy that alternates between individual message flooding and random gossiping, and [13] applies Schelling's model that individuals always move to their final groups where they are satisfied with their neighborhoods, and proposes a push based scheme for dense network areas to maximize query hit and a pull based scheme for sparse network areas to utilize network bandwidth. Moreover, incorporating social analysis, [14] utilizes the community and centrality social metrics in forwarding decisions in a social based forwarding protocol—BUBBLE, and [15] classifies mobile device users according to their social behaviors, where socials show up frequently or periodically while vagabonds represent the rest also majority of the population, and then shows how each classification affects data dissemination.

Recently, [1] introduces a specific form of data dissemination—spatial dissemination, which aims at sending information from mobile users to other mobile users who are or will appear at a user defined region. It develops the Sticker dissemination protocol leveraging the concepts from disruption-tolerant networks (DTN) to tolerate message delivery disruption. Sticker adopts the store-carry-forward model and exploits human mobility to facilitate message forwarding and delivery. However, Stickers treats users separately without taking into account user groups. We believe by applying group dynamics to spatial dissemination, we can have a more cost-efficient approach.

## III. Problem Description

We first introduce a concept 'SoI' (Source of Information) to represent the location where mobile users can obtain new information. We consider a user group as a group of mobile users that move together or be present at the same place around the same time. Assume there is a SoI, an influence range $R_i$ inside which users directly get new information, and a dissemination range $R_d$ inside which information is intended to reach users, a user set $U$ inside the influence range of a SoI where each user has transmission range $r$. Users inside the influence range can communicate directly and are assumed location aware (e.g., equipped with GPS). As shown in Fig. 1, there is a SoI represented by a square and mobile users represented by triangles, some of which are in user groups. The dashed circle and the solid circle show the influence range $R_i$ and the dissemination range $R_d$ of the SoI, respectively. In addition, the dotted dashed circle shows the transmission range $r$ of the corresponding user. Moreover, the users inside $R_i$ can obtain the SoI related information and initiate the corresponding messages, while other users inside $R_d$ are considered as consumers related to the SoI.

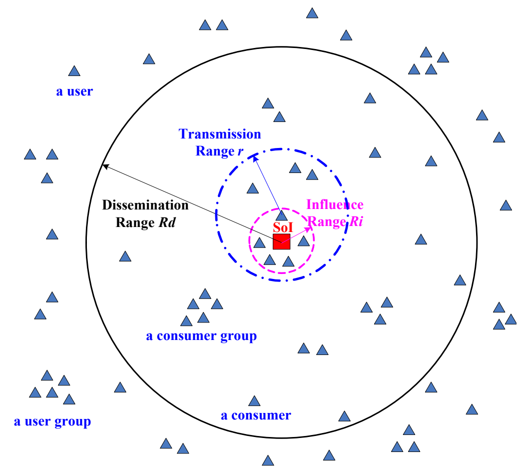


Fig. 1. A sample scenario of group enabled spatial dissemination

We also assume a message $M$ with lifetime $T$ (i.e., valid for $T$ time units) is disseminated by a user within $U$. $M$ should be received by users inside the dissemination range centered at SoI at any time before $T$ expires. Since users within a user group are likely to be geographically close to each other and share the same information, the problem is to find a solution to achieve an optimal message delivery ratio while incurring minimum storage and transmission costs. The message delivery ratio here is defined as the ratio of the number of users that receive $M$ over the total number of users inside $R_d$ of the SoI within $T$. i.e., the goal is to disseminate the messages to as many users as possible who are inside the dissemination range of the SoI within $T$.

**System Model:** We adopt the store-carry-forward model as in Sticker [1]. Certain mobile users are selected among their user groups as message carriers to store message copies in their mobile devices which have cache limits. When a message is 'forwarded' (i.e., to a non consumer of the SoI), the sender does not keep a copy; when a message is 'delivered' (i.e., to a consumer of the SoI), the sender typically still keeps a copy, but the sender does not keep a copy if the receiver is a better candidate to store and carry the message.

## IV. Group Enabled Spatial Dissemination

The group enabled spatial dissemination proposed in this paper consists of six components on each mobile device as shown in Fig. 2. The Localization and Neighbor Discovery modules provide underlying services to support group management: the *Localization module* simply provides current location of the mobile device, while the *Neighbor Discovery module* periodically reports the current location and records the neighboring mobile devices with their locations. The *Group Management module* forms and maintains user groups, provides group information to the upper layer services, and shares information among group members. The *Replication, Forwarding, and Purging modules* are the upper layer services in the dissemination process which utilize group management for spatial dissemination: the replication module decides the amount of message copies that should be maintained in the network and whether a message copy should be retained after forwarding, the forwarding module decides whether a message copy should be forwarded from one user to another for a better location to store, and the purging module decides whether an existing message needs to be deleted to make room for an incoming message if the cache overflows. The details of group management and dissemination process are as follows.

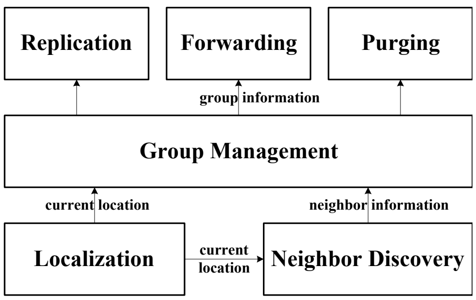


Fig. 2. Key components of group enabled spatial dissemination

### *A. Group Management*

User groups in mobile social networks are dynamically changing, so it is important that group management be up to date with the current status. The group management component uses the location information of mobile devices and their neighbor information to decide how the initial groups should be formed, how each group is maintained, and what information should be included in the group history.

**Group formation:** After neighbor discovery in each period $P$, each user identifies a temporary local user group containing current users within the mobile device's transmission range $r$.

**Group maintenance:** A neighbor duration threshold $Th_d(\geq P)$ is used to keep track of the local user group. A user who stays within a local user group for no less than $Th_d$ time units is considered as an eligible neighbor. After the neighbor discovery in each period, each user records a local user group containing eligible neighbors into the group history.

For instance, Fig. 3 shows the temporary local user group of user $u_1$ in each time period. Assume $Th_d = 3P$. Then, after $P$, the temporary local user group of $u_1$ has members $\{u_1, u_2, u_3\}$. After $2P$, the members are $\{u_1, u_3, u_4\}$. After $3P$, the members are $\{u_1, u_3, u_4\}$, and the group consisting of $\{u_1, u_3\}$ is recorded into the group history. Similarly, the group consisting of $\{u_1, u_3, u_4\}$ is recorded into the group history after $4P$, the group consists of $\{u_1, u_3\}$ after $5P$, the group consists of $\{u_1, u_2, u_3\}$ after $6P$, and the group consists of $\{u_1, u_3\}$ after $7P$.

**Group history:** The group history stores the most recent record of the group, containing group size (i.e., group members), group validation time (i.e., the time period when the group is recoded into the group history), and group location

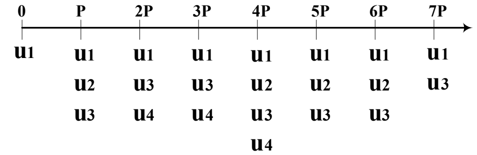


Fig. 3. Sample group formation and maintenance

(i.e., the latest average location of the group members). In each neighbor discovery period, the historical group size is broadcasted along with the user ID, current location, and available cache size of the mobile device. This information is used when making replication decisions.

### *B. Group-enabled Spatial Dissemination*

The overall dissemination process works as follows. At any time, there might be any number of users inside $R_i$ of a SoI, and the SoI might provide new information. An initial message is sent out when a user inside $R_i$ of a SoI first notices new information from the SoI and broadcasts a message regarding the new information including the source user and location. The other users inside $R_i$ of the SoI receiving the message will not generate the same messages for the information, but only participate in the dissemination process. After the initial message broadcasting, replication and forwarding take place after each round of neighbor discovery, and purging is applied if the cache overflows.

To minimize the dissemination costs including both storage and transmission costs, group information is used in the dissemination process. More specifically, the first user inside a user group that is chosen by the replication or forwarding strategy will replicate or forward the message. If appropriate (e.g., the group has only a few users and they are all located relatively close to each other), other users in the group do not need to replicate or forward the message. Group information is also used in purging to take advantage of available storage space of other group members. A more solid way to use group information will be investigated in our future work.

*1) Replication:* The goal of the replication strategy is to minimize the number of message copies in the network. This is achieved by keeping the minimum number of message copies for each user group. The number of copies for each group varies over time according to the distribution of users. Determining an optimal number of copies for each group over time remains as part of our future work.

In the replication strategy, a user makes the following decisions upon receiving a new message: a) discard the message; b) store a message copy; c) store a message copy after purging; d) store a message copy and ask the sender to delete the message. If a sender is inside the dissemination range of the SoI, only the receivers who are inside the dissemination range of the SoI may replicate the message. However, if a sender is outside the dissemination range of the SoI, all the message receivers who are closer to the SoI than the sender may replicate the message, regardless of whether the receiver is inside or outside the dissemination range. Whether a receiver will replicate the message or not is determined by the forwarding strategy.

Upon receiving a message, a user checks the stored messages in the device cache, the sender's location included in the incoming message, his current location, his current temporary local user group, and his historical group to make a replication decision. If the incoming message exists in the cache (i.e., there is a stored message that has the same message ID, SoI location, and sender user ID as the incoming message), then the user simply discards this incoming message if this is a broadcasting message, or the user might notify the sender to delete the message if this is a forwarding message targeted at this receiver (using *forwarding strategy*). Otherwise, group information will be used for replication decision (as shown in Fig. 4) and purging decision.

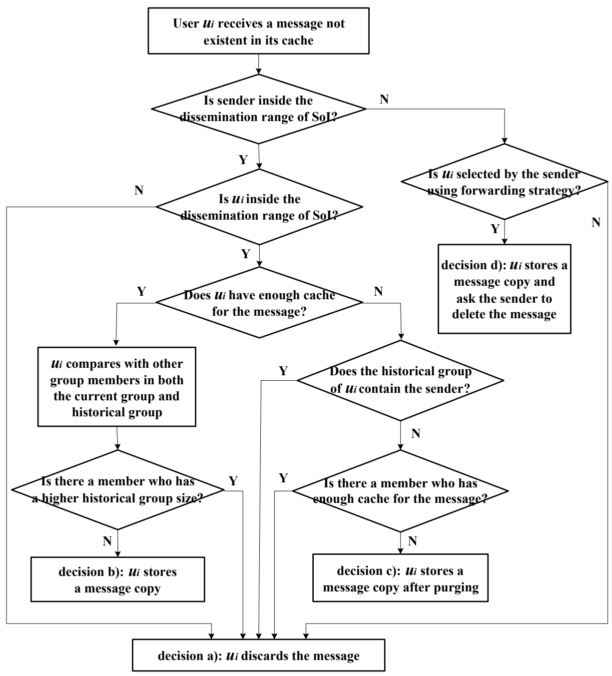


Fig. 4. The replication strategy

*2) Forwarding:* The forwarding strategy decides whether a user who has stored a message copy should forward the message to other users. The goal is to minimize the transmission cost, so the users who have stored messages only broadcast the messages when there are potential consumers or forward the messages to those who are more suitable to store them. After discovering neighbors in each neighbor discovery period, each user who has stored messages checks his current location, current temporary local user group, and historical group to decide if there are messages to broadcast or forward and finally makes the forwarding decisions including the target receivers. The detailed process is shown in Fig. 5.

*3) Purging:* The purging strategy deals with cache overflows on each mobile device. We try not to replace any existing messages as long as there is at least one member inside a user group who has enough space to store an incoming message.

As discussed in the *replication strategy*, if a message receiver does not have enough available cache to store the message, a group member who has enough available cache will store the message instead. In this way, messages are cached

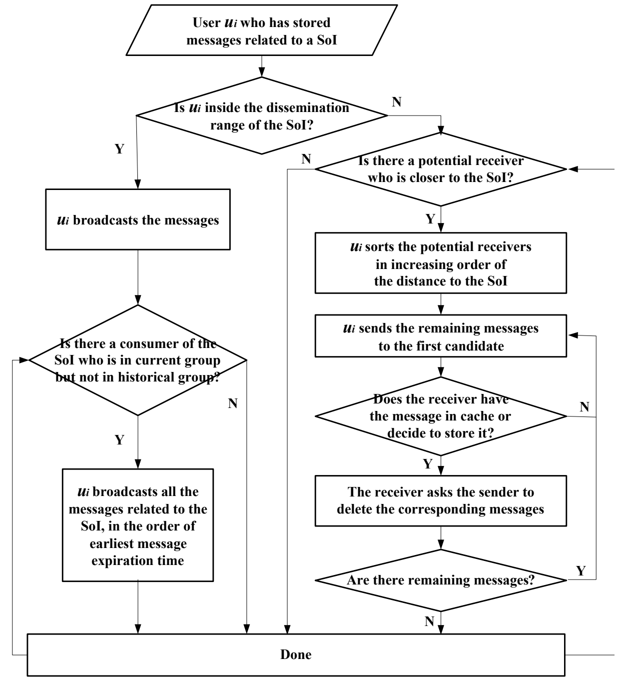


Fig. 5. The forwarding strategy

among user groups. However, if none of the group members have enough cache available, then the receiver will use the following local purging strategy to decide whether and which existing messages to replace.

A utility metric called Message-Significance (MS) for message $M$ is designed as $MS_M = Tl_M/(1+Dr_M)$, where $Tl_M$ is the remaining lifetime of $M$ and $Dr_M$ is the relative distance between the message location (i.e., the current location of the device that caches $M$) and the related SoI dissemination area. If $M$ is currently inside the dissemination range of the related SoI, then $Dr_M = 0$. Otherwise, $Dr_M$ is calculated as the distance from $M$ to the SoI location minus $R_d$.

Based on the MS metric, a greedy approximation algorithm [16] used to solve the NP-hard 0-1 knapsack problem can be applied to decide which messages to replace. The message receiver creates a purging candidate set which includes the existing messages whose MS values are smaller than the incoming message, and sorts the candidates in increasing order of the MS value (using message size as tie breaker). Then, the message receiver sequentially adds the sorted messages to a purging schedule until the total size of the messages scheduled exceeds the size of the incoming message. If there exists such a purging schedule, then the scheduled messages will be replaced by the incoming message. Otherwise, the incoming message will be rejected.

## V. Performance Evaluation

We implemented a middleware layer simulator in Python to simulate user movements and message transmissions rather than the underlying networks. The performance metrics we consider are (i) delivery ratio: the percentage of users receiving a SoI related message out of all the users in the SoI's dissemination range during the message's lifetime. (ii) transmission cost: the number of times a message is transmitted, normalized over the number of devices receiving the message. (iii) storage cost: the sum of time that a message is cached on each device, normalized over the message's lifetime.

The variable experimental parameters are shown in Table I, where the normalized message range is the dissemination range to transmission range ratio $R_d/r$. In addition, there are fixed parameters set similarly to Sticker [1] as follows : network area—1000m*1000m; simulation time of each run—3600s; number of SoIs—25; transmission range $r$—38m; SoI influence range $R_i$—18m; neighbor discovery period—6s; neighbor duration threshold—2; user stay duration—1s (min) and 40s (max); SoI information update interval—60s (min) and 600s (max); message lifetime—60s (min) and 600s (max); message size—0.1KB (min) and 1KB (max); minimum node speed—0.5m/s.

TABLE I
VARIABLE EXPERIMENT PARAMETERS

| Parameter | Value Range | Default |
|---|---|---|
| Normalized message range | 1.0,1.5,...,4.0 | 3.0 |
| Number of mobile nodes | 40,60,...,160 | 100 |
| Cache capacity | 1,2,...,64 (KB) | 16KB |
| Max node speed | 2,3,...,8 (m/s) | 2 |

**Experiment Setup:** Each simulation run lasts 3600 seconds simulation time. In each run, the simulator first initializes a number of SoIs randomly in a 1000m*1000m area, where each SoI has an influence range $R_i$ and a dissemination range $R_d$ according to the input parameters. A number of mobile users are initialized with random locations, and they travel linearly towards SoIs that are randomly selected, with a random speed between the min and max speeds and a random duration between the min and max stay durations when they arrive at their target SoIs. After stay inside the $R_i$ range of a SoI, a user randomly selects a different SoI with a random speed and travels toward the new SoI. During the simulation, each SoI updates its information that is aware of users inside $R_i$ with a random update interval between the min and max update intervals, while the first user who is aware of an update of SoI information creates a message with random size and lifetime both between their min and max values. This process repeats until the simulation run ends.

**Experimental Results:** We compare our approach with epidemic dissemination approach. In epidemic dissemination approach, users send their messages to every user they encounter, and users store every message they receive while replace the earliest messages when their device caches overflow. The impact of the variable experiment parameters on the performance metrics are shown in Fig. 6, Fig. 7, Fig. 8, and Fig. 9, where all the results are based on 10 simulation runs with random initial setups. Fig. 6(b), 7(b), 8(b), and 9(b) show that the Group-Enabled approach proposed in this paper has much lower transmission cost than Epidemic, while Fig. 6(c), 7(c), 8(c), and 9(c) show that the storage costs are also much lower in the Group-Enabled approach. However, as shown in Fig. 6(a), 7(a), 8(a), and 9(a), the delivery ratio of the Group-Enabled approach is slightly lower than Epidemic. As a baseline, Epidemic has the highest delivery ratio comparing with other approaches in most scenarios. In summary, comparing with Epidemic, the Group-Enabled approach proposed in this paper is efficient in both transmission cost and storage cost, and the delivery ratio is very reasonable as a trade off. The ongoing work will implement Sticker in the same simulation environment for comparison.

## VI. CONCLUSIONS AND FUTURE WORK

This work has developed a spatial dissemination protocol that uses mobile user groups information in mobile social networks. The experimental results have shown that the proposed approach incurs lower transmission and storage costs than Epidemic while achieving similar delivery ratio in many scenarios. Our future work will improve and extend this work in several aspects. First, the group management and the three main strategies used in this work are simple tentative solutions. They will be improved by employing utility metrics. For instances, a user proximity threshold might be applied to the group formation instead of simply using the device transmission range, and utility metrics might be applied to the replication and forwarding decisions instead of simply comparing the locations and group properties. Second, this work is a pure push-based dissemination protocol. Advantages of combinations of push and pull based approaches have been shown in both [13] and some distributed publish-subscribe systems [17]–[20]. Therefore, we will apply a combination of push and pull techniques to provide more efficient data services in terms of both dissemination and query.

## ACKNOWLEDGEMENT

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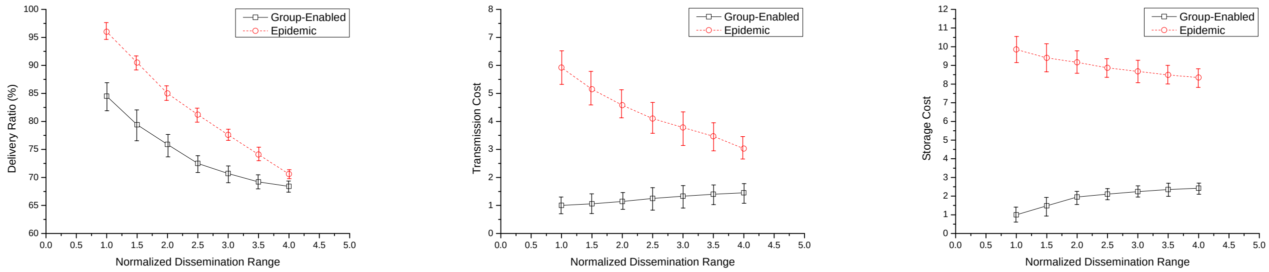
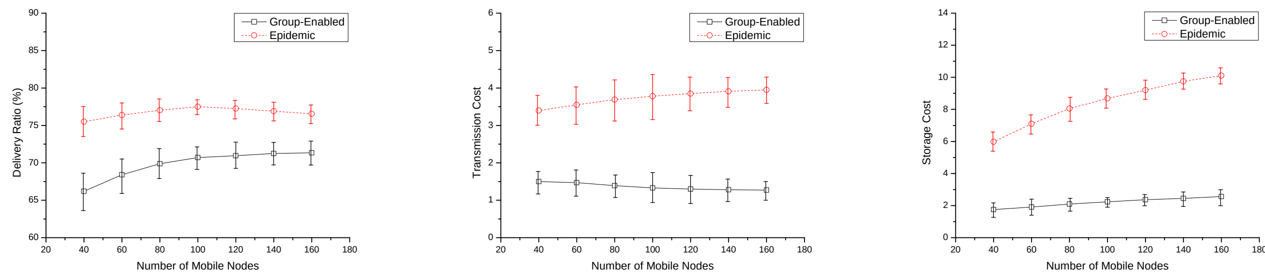


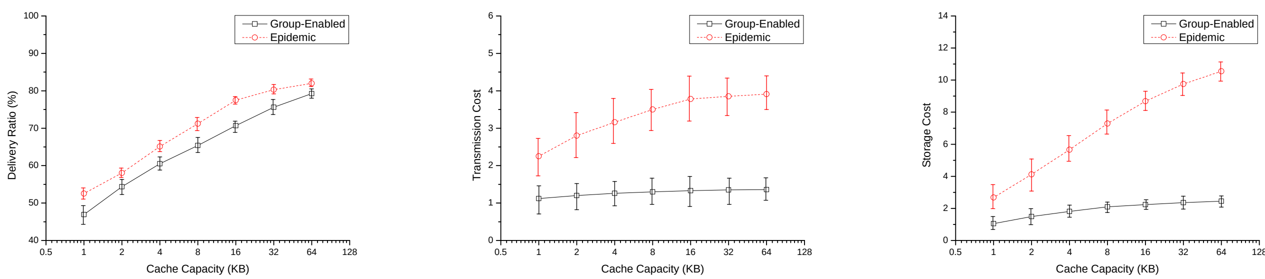

(a) (b) (c)

Fig. 6. Impact of Normalized Dissemination Range



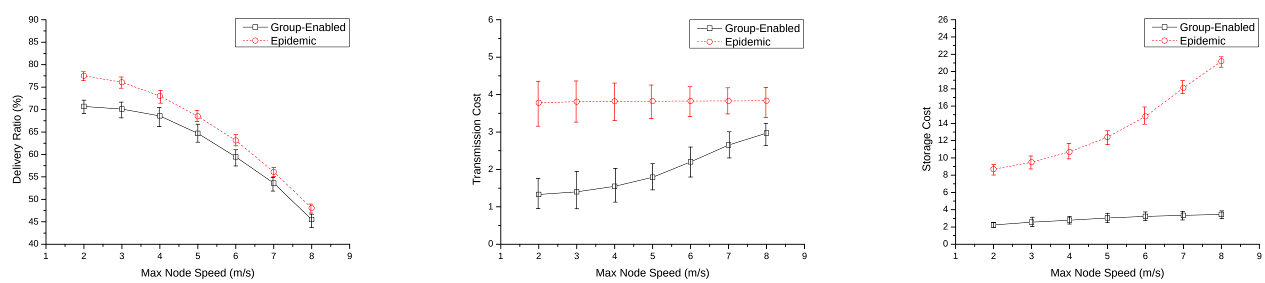

(a) (b) (c)

Fig. 7. Impact of Mobile Node Density




(a) (b) (c)

Fig. 8. Impact of Cache Capacity




(a) (b) (c)

Fig. 9. Impact of Max Node Speed

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